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COMPUTER-BASED SIMULATIONS FOR MAINTENANCE TRAINING: CURRENT ARI RESEARCH

Bruce W. Knerr, Zita M. Simutis,
and Richard M. Johnson

SYSTEMS MANNING TECHNICAL AREA

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ue on reverse side if necessary and identify by block number) The Army Research Institute
conducting three research efforts that use computer-based
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n individuals to maintain actual equipment. The Adaptive Comput-
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student with generalizable diagnostic skills rather than equipment-specific procedures. This report describes the techniques being developed, research findings, and future research directions.

Technical Report 544

COMPUTER-BASED SIMULATIONS FOR MAINTENANCE TRAINING: CURRENT ARI RESEARCH

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Maintenance Training

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FOREWORD

The Manpower and Educational Systems Technical Area of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) performs research and development that includes the application of educational technology and simulations to military training. Research on the use of computer-based simulations for maintenance training is of special interest because the development and implementation of such simulations is seen as a means of reducing training time and costs. Computer-based simulations can provide greater individualization of training than standard approaches and can reduce the need for operational equipment during training.

This report summarizes three on-going research efforts concerned with computer-based simulations for maintenance training. It is an edited version of an unpublished paper presented at the Military Operations Research Society Symposium in December 1979.

The first effort, Game-Based Learning, is being conducted by in-house personnel. It is responsive to the requirements of RDT&E Project 2Q262717A790, "Human Performance Effectiveness and Simulation," as described in the ARI FY 80 Personnel Performance and Training Program: Basic Research and Exploratory Development.

The second effort, Human Performance in Fault Diagnosis Tasks, is being conducted by the University of Illinois as part of the ARI Research Themes Program. The research is responsive to the requirements of RDT&E Project 2Q161102B74F, "Basic Research in the Behavioral and Social Sciences."

In order to accomplish the third effort, Adaptive Computerized Training System, ARI's resources were augmented by contract with Perceptronics, Inc., an organization selected as having unique capabilities for research and development in this area. The research is responsive to the requirements of RDT&E Project 2Q263744A795, "Training Simulation," as described in the ARI FY 80 Personnel Performance and Training Program: Advanced Development.

JOSEPH ZEIDNER
Technical Director

COMPUTER-BASED SIMULATIONS FOR MAINTENANCE TRAINING: CURRENT ARI RESEARCH

EXECUTIVE SUMMARY

Requirement:

Current Army maintenance training is largely equipment specific. The student is first taught the step-by-step procedures necessary to locate the malfunction in a specific item of equipment, then spends time practicing, and finally is tested on the equipment itself. Because the training content consists of equipment-specific procedures rather than more general troubleshooting logic, there is little likelihood of transfer of the skills acquired to other items of equipment that the student will encounter on the job. This lack of transfer is reflected in the relatively high proportion of functional components submitted for repair (42% in one study). In addition, this current training approach makes inefficient use of student time, instructor time, and equipment, thereby inflating costs. Efficient methods for providing training in generalizable diagnostic skills could reduce costs and improve on-the-job skills.

Procedures:

Three research efforts that use computer-based simulations for maintenance training are being conducted. Game-Based Learning investigates the use of computer-based games to teach diagnostic skills. Human Performance in Fault Diagnosis Tasks evaluates the use of context-free tasks to train individuals to maintain actual equipment. The Adaptive Computerized Training System applies "artificial intelligence" techniques to electronic troubleshooting training.

Findings:

The findings to date, while incomplete, suggest that each of the approaches can improve maintenance performance under certain conditions. Playing a logical game is an effective substitute for training in reading logic circuit diagrams and practice solving context-free diagnostic tasks enhances subsequent performance when diagnosing faults in equipment-specific simulations. Although the Adaptive Computerized Training System has yet to receive rigorous experimental evaluation, its feasibility has been demonstrated.

Utilization of Findings:

Research will continue to improve the described techniques and to evaluate them under conditions that are more representative of the Army training environment. Guidelines for developing and using games for training will be developed. The effects of training with context-free tasks on the subsequent maintenance of actual equipment will be investigated. The cost and training

effectiveness of the Adaptive Computerized Training System will be evaluated in an on-going course of instruction at an Army school.

COMPUTER-BASED SIMULATIONS FOR MAINTENANCE TRAINING: CURRENT ARI RESEARCH

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COMPUTER-BASED SIMULATIONS FOR MAINTENANCE TRAINING: CURRENT ARI RESEARCH

INTRODUCTION

This report describes three efforts in the area of computer-based simulations for maintenance training currently being conducted by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). ARI is interested in the use of computer-based simulations for maintenance training because it provides a potential means of overcoming some of the problems in this area that the Army currently faces.

The first problem for efficient maintenance training is the increasing number and complexity of Army systems. Not only is equipment becoming more difficult to maintain, but there is more of it. The second problem is that the skill level of the pool of manpower available for military service is declining. Unless social or economic changes increase the desirability of military service or the civilian educational system improves, future military maintenance personnel will require additional or improved training to reach the same level of proficiency that current personnel achieve with existing training. The third problem is that the number of people available for military service is decreasing and will continue to do so until the late 1990s (Baker, 1980). All other factors being equal, therefore, the skill levels of entering personnel are expected to be even lower in the future. Army schools must deal with these problems while facing increased operating costs and reductions in personnel.

The limited data available suggest that improved maintenance performance could produce a substantial improvement in readiness. Dressel and Shields (1979) measured organizational-level maintenance performance in a brigade-size unit during a 1-year period. They collected data on selected end items of the M551 armored reconnaissance airborne assault vehicle turned in for exchange at a direct support maintenance facility. Figure 1 shows, by month, the total number of submissions and false removals (items submitted as defective that were, in fact, functioning properly). Overall, 42% of the total items submitted were false removals, and 32% of the repair time at the direct support level was spent determining that false removals were operating correctly. This represents an average of 1.5 hours per item, only .8 hours less than the time required to repair a faulty item. Furthermore, 30% of equipment downtime was due to these false removals. Thus, a considerable amount of operational and maintenance time is lost because working equipment is removed for repair.

Two caveats regarding these data should be noted. First, they do not represent a random sampling of Army maintenance performance (although there is no reason to believe that they are atypical). Second, the performance observed undoubtedly reflects a number of factors other than the quality of maintenance training per se, such as command pressures, misassignments, and personnel turbulence. The data do, however, clearly establish the existence of a maintenance problem. This problem may not be unique to the Army, or even to the military, but there are no comparable data available from other sectors.

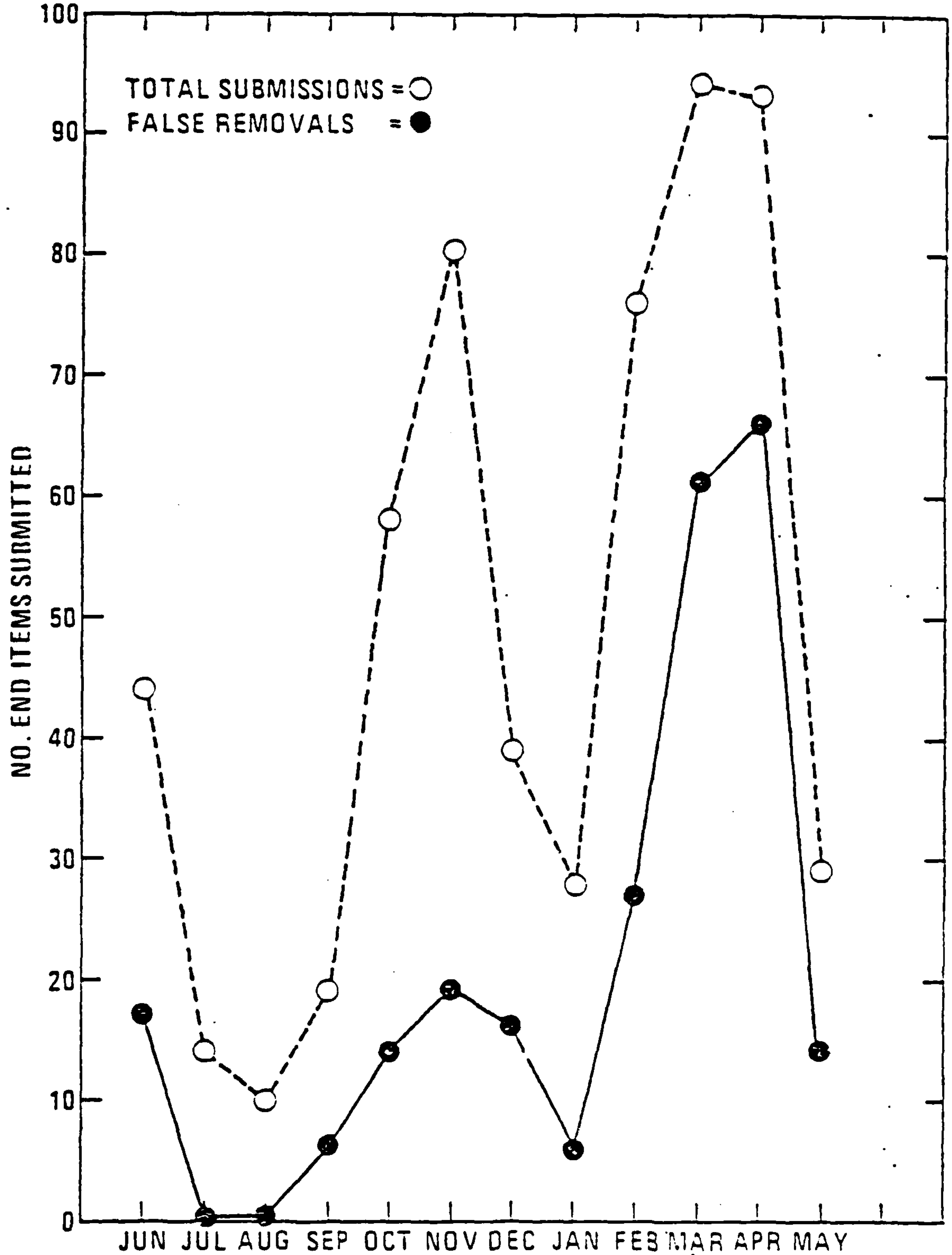

Figure 1. Number of items submitted for repair, by month (from Dressel & Shields, 1979).

The Army currently follows primarily a hands-on and equipment-specific approach to maintenance training. The student is first taught the sequential step-by-step procedures necessary to locate a malfunction in a particular item of equipment, then spends time practicing, and finally is tested on the equipment itself. This approach has several advantages. It ensures that the student has mastered certain prerequisite skills, such as the use of test equipment. It teaches the student the physical layout of the equipment and its relationship to functional or schematic diagrams. Finally, the student practices assembling and disassembling an actual piece of equipment.

There are also some disadvantages to this training approach, however. First, time constraints do not permit the student to receive training on all of the equipment that is expected to be encountered on the job. Because the training content consists of equipment-specific procedures, rather than troubleshooting logic, there is little likelihood of transfer of the skills acquired to other items of equipment. Second, a substantial amount of equipment, which could otherwise be used operationally, is required for training. Third, instructors must spend large portions of their time inserting malfunctions into equipment, rather than actually conducting training. Fourth, a large amount of student time is spent assembling and disassembling the equipment, thus reducing the number of different malfunctions that they can experience during training.

Computer-based simulations provide a means to overcome these disadvantages. They can reduce the need for actual equipment for training and can reduce the amount of instructor time devoted to "faulting" equipment. By eliminating the need for time-consuming assembly and disassembly by the student, they provide more opportunity for the student to experience a larger set of equipment faults. They can provide more efficient training by adapting to individual differences in performance. More important, they have the potential to provide the student with generalizable diagnostic skills that can be applied to a variety of items of equipment. Finally, because computer costs are rapidly decreasing they can be expected to be inexpensive, in comparison to the use of actual equipment, in the near future.

The first research effort to be described is called Game-Based Learning. Its objective is to determine the training effectiveness of games and to develop procedures for the design and use of games for training (Baker, 1981). While the scope of this research goes beyond the area of maintenance simulation, the early work has used maintenance training tasks.

The second effort is Human Performance in Fault Diagnosis Tasks. One objective of this research is to investigate the use of "context-free" diagnostic tasks to train individuals to maintain real equipment. This work is being performed by Dr. William Rouse, of the University of Illinois, under a contract with ARI.

The objective of the third effort, the Adaptive Computerized Training System (ACTS), is to evaluate the use of artificial intelligence techniques for electronic troubleshooting training. Most of the work has been performed by Dr. Amos Freedy, of Perceptronics, Inc., under contract to ARI.

GAME-BASED LEARNING

Background

The recent increase in the use of instructional games within the educational, industrial, and business communities can be attributed to the high interest and motivation they appear to generate among users. Games also appear to provide a simulated environment within which information acquisition, information processing, and decision-making skills can be developed and maintained. Yet, even though the use of gaming techniques for instruction and training has intrinsic appeal, there is very little systematic evidence that instructional games actually teach what they are designed to teach. Further, aids to assist instructional game developers in designing training-effective games do not exist because there is insufficient behavioral data on the critical learner and task variables in game-based learning.

The purpose of ARI research in game-based training is to conduct a systematic assessment of the training effectiveness of games and to investigate their full potential as training media. To date, one experiment has been conducted (Simutis, Baker, Bersh, & Alderman, 1979) and a second is in progress. Both have used a similar approach: measuring the transfer of training from a problem-solving game to simulated electronics maintenance tasks. The first experiment measured transfer of training to the reading of logic circuit diagrams. All subjects received some instruction and practice on this task before they were tested. Three groups of subjects received additional paper-and-pencil practice reading these diagrams, played a computerized logic game, or played a computerized game of chance. The second experiment uses troubleshooting of a simulated computer circuit as the transfer task. While the experimental groups are essentially the same as in the first experiment, an additional control group has been added and exposure to computers has been controlled by providing all training, practice, and testing by computer.

Experiment 1

In Experiment 1, 42 enlisted personnel from Fort Belvoir, VA, were randomly assigned to one of three experimental groups: Logic Control, Logic Game, or Control Game. The experimental design is shown in Figure 2. Each group participated in three 1-hour training or practice sessions, followed by a transfer task.

Students in the Logic Control group first received 1 hour of instruction on the interpretation and meaning of five logical functions (AND, OR, NAND, NOR, and INVERSION) and other features of logic circuit diagrams. Following this, they received 2 hours of practice reading logic diagrams. Six levels of complexity (A through F) of the logic diagrams were used. Levels differed in one or more of the following ways: the number of different logic functions, the total number of logic elements, and the number of inversions. Figure 3 shows a very simple logic diagram (Level A). It contains two different logic functions (AND and OR), three logic elements, and no inversions. A moderately complex diagram (Level C) is presented in Figure 4. It contains all of the logical functions, seven inversions, and 12 logical elements. The students' task was to determine the outputs of each diagram. Students progressed through the diagrams in order of increasing complexity. Only subjects

Group	Session			
	I	II	III	IV
Logic Control	logic symbol instruction	logic diagram practice	logic diagram practice	transfer test
Logic Game	Mastermind	logic symbol instruction	logic diagram practice	transfer test
Control Game	Blackjack	logic symbol instruction	logic diagram practice	transfer test

Figure 2. Experimental design for Experiment 1.

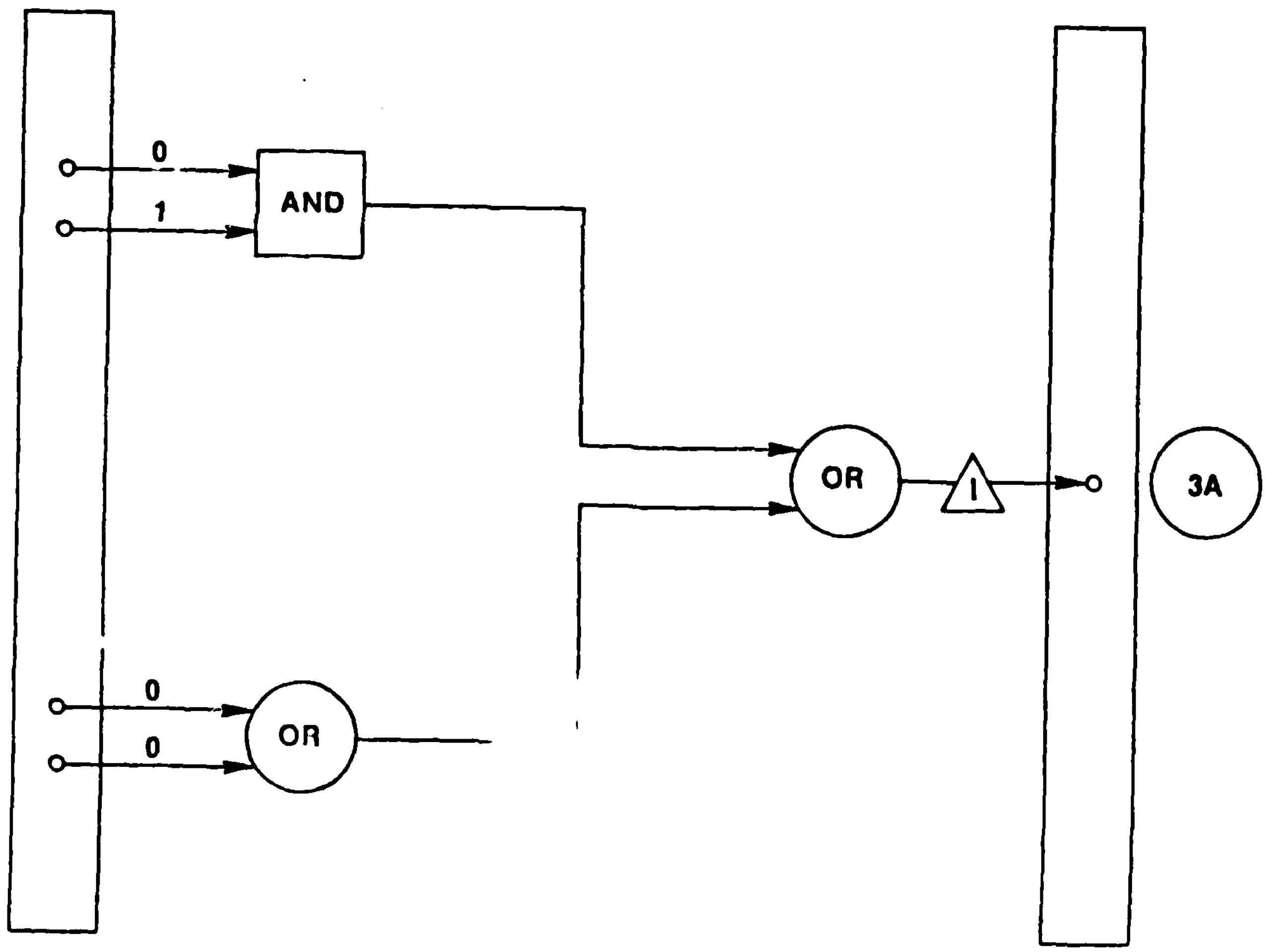

Figure 3. A very simple logic diagram (Level A).

in the Logic Control group received practice in all levels of diagrams. Subjects in the other groups practiced only on Level A, B, and C diagrams. Each diagram had the correct answer(s) penciled on the back. Subjects received feedback by checking their answers after completing the diagrams.

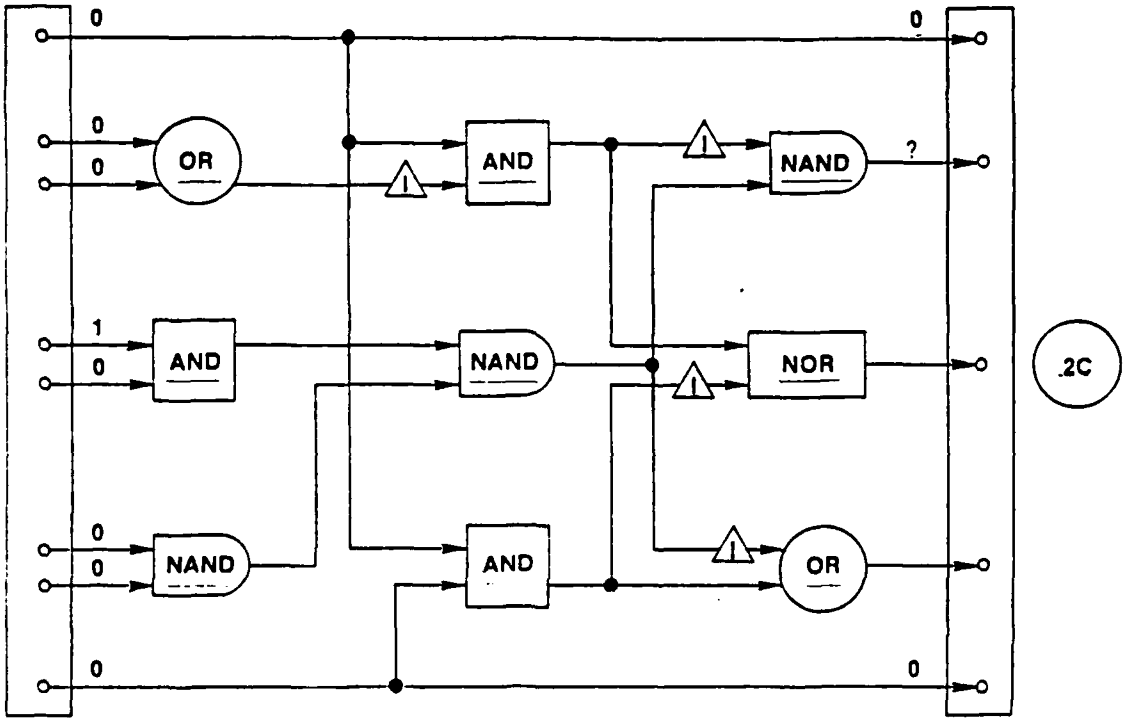

Figure 4. A moderately complex logic diagram (Level C).

During the transfer test the subjects were given 1 hour to solve 40 new logic diagrams, 10 diagrams from each of the four highest levels of complexity. Subjects began with the least complex problems. No feedback regarding the correctness of their responses was given.

Subjects in the Logic Game group spent the first hour of their training playing a computerized version of the game Mastermind, presented on the University of Illinois PLATO IV system. This game required the subjects to determine a hidden sequence of four digits that had been sampled without replacement from the digits 1 through 8 and randomly assigned to positions. The first game trial was necessarily a guess, and after each trial feedback on the accuracy of the guess was provided. The subjects were told (a) how many digits in the guess were correctly identified and placed in the correct sequence position and (b) how many digits in the guess were correctly identified but had been placed in the wrong position. This information could be used to eliminate wrong alternatives on subsequent guesses. If the subject had not discovered the correct solution within eight trials, the solution was shown and a new game begun. A different random sequence of digits was

generated for each subject for each game. Following the Mastermind session, the Logic Game group received the logic symbol instruction, the logic diagram practice, and the transfer test. The only difference from the training received by the Logic Control group was that the practice included only the three least complex levels of circuit diagrams.

The Control Game group spent the first hour of training playing a computerized version of Blackjack, also presented on the PLATO IV system. Subjects played against the computer and were given an initial stake of $1,000. If they lost their stake, they were provided with an additional $1,000. The game rules were the traditional Blackjack rules. The logic symbol training and practice provided to the Control Game group were identical to the training and practice received by the Logic Game group.

The transfer task was scored for both accuracy and performance. The accuracy score is the proportion of items attempted for which the subject gave the correct answer. The performance score is the proportion of total items for which the subject gave the correct answer.

Table 1 summarizes the group means at each of the four levels of diagram complexity (C, D, E, and F) used on the transfer task. The accuracy and performance scores are similar except at the highest level of complexity (Level F). Recall that the subjects in the Logic Game and Control Game groups were not exposed to diagrams as complex as those represented by Levels D, E, and F prior to the transfer task. Recall also that the level of complexity of the diagrams was confounded with time, with the most complex diagrams being encountered last. (The fact that some subjects were unable to complete all of the diagrams, then, explains the relatively large differences between the accuracy and performance scores found in Level F.)

Table 1

Accuracy (A) and Performance (P) Scores

	Diagram complexity				
Group	C	D	E	F	G
Logic Control					
A	.92	.90	.90	.80	.86
P	.89	.88	.89	.74	.85
Logic Game					
A	.61	.71	.82	.67	.70
P	.58	.70	.79	.65	.68
Control Game					
A	.65	.62	.68	.58	.60
P	.63	.62	.68	.49	.60

The pattern of significant results obtained indicates two general trends, evident on the graph of the performance scores shown in Figure 5. First, the Logic Control group was superior to the Control Game group. The Logic Game group was in the middle, significantly worse than the Logic Control group in terms of accuracy scores, but not performance scores, and significantly better than the Control Game group in terms of performance scores, but not accuracy scores. The second trend is that the Logic Game group performed more like the Control Game group on the diagrams of intermediate complexity (Levels C and D) and more like the Logic Control group on diagrams of high complexity (Levels E and F).

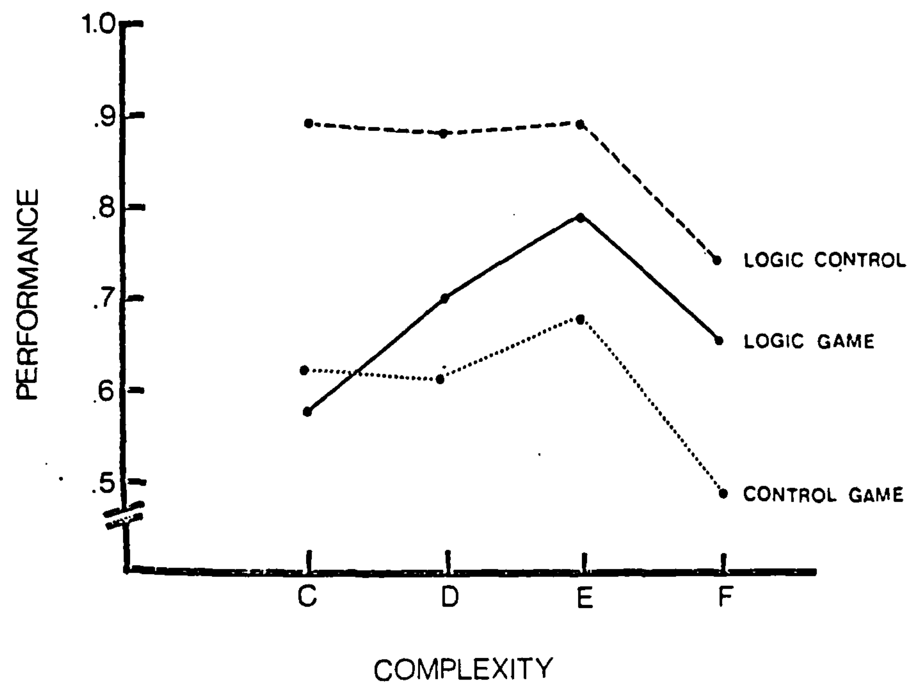

Figure 5. Performance scores as a function of diagram complexity.

These results indicate that under certain conditions limited practice in reading logic circuit diagrams, when combined with playing a logic game like the one used here, is as effective as the same amount of time spent in practicing reading a more extensive set of diagrams. This is not true when the limited practice is combined with playing a game of chance, so results cannot be attributed to any general transfer effects of game playing per se. Because both game groups had the same practice set of diagrams, yet significantly different accuracy and performance scores at some diagram levels, it also cannot be argued that limited practice was sufficient for successful performance on the transfer test.

The results also raised a number of questions. The Logic Game and Control Game groups were exposed to a computer. The Logic Control group was not. Was this a factor in the results? Why did the Logic Game group do relatively better on the high-complexity diagrams (Levels E and F) than on the diagrams of intermediate complexity (Levels C and D)? Did this indicate a motivational letdown caused by transferring from a highly challenging game to the relatively

boring task of reading logic circuit diagrams? A second experiment was designed to answer these questions.

Experiment 2

Figure 6 shows the design for Experiment 2, which is currently in progress. It incorporates three major changes from Experiment 1. First, it includes a "pure" Control group. This group will permit a determination of whether game playing (either Blackjack or Mastermind) is better than no additional practice. Second, all training and testing is being done by computer, eliminating the possibility that any effects could be caused by exposure to computers. The computer-based courseware is described in Yeager and Simutis (1979). Finally, the transfer task has been changed from reading logic diagrams to troubleshooting simulated logic circuits.

	Session			
Group	I	II	III	IV
Logic Control	logic diagram instruction & practice	fault isolation instruction & practice	additional practice	transfer task
Logic Game	logic diagram instruction & practice	Mastermind	fault isolation instruction & practice	transfer task
Control Game	logic diagram instruction & practice	Blackjack	fault isolation instruction & practice	transfer task
Control	logic diagram instruction & practice	fault isolation instruction & practice	transfer task	

Figure 6. Experimental design for Experiment 2.

Future Directions

The results of these experiments will provide data on the effectiveness of a logic-based game for training in electronics tasks. Future research is planned to replicate the first results and to explore the effects of individual differences on game-based training.

HUMAN PERFORMANCE IN FAULT DIAGNOSIS TASKS

Background

The research in "Human Performance in Fault Diagnosis Tasks" assumes that some skills are common to all fault diagnosis tasks. Clearly, equipment-specific

skills are important; an electronic technician would not be expected to be able to diagnose a faulty aircraft engine, nor would an aircraft mechanic be expected to be able to repair a radio, yet these tasks do have common elements.

Dr. William Rouse and his associates at the University of Illinois have been evaluating the use of "context-free" fault diagnosis tasks for training in diagnostic skills. Context-free tasks do not represent any particular item or type of equipment. The research strategy has been to examine the transfer of training from one context-free task to another, and from context-free tasks to equipment-specific tasks. In addition, the use of computer aiding is being investigated. Computer aiding represents a synthesis of unassisted human fault diagnosis and the use of automated test equipment.

The Tasks

The term context-free task is best explained by example. Figure 7 shows a simple context-free task that will be referred to as Task 1. This display is presented to the student on a computer terminal. The network consists of a 7 x 7 matrix of components, numbered 1 through 49. The arcs connecting the components are selected at random and are different each time the student diagnoses a new network. Each component is an AND gate. If all of the inputs to that component are 1, and if the component is good, the output of that component will be 1. If any of these conditions is not satisfied (that is, if any input is 0, or if the component is faulty), the output will be 0.

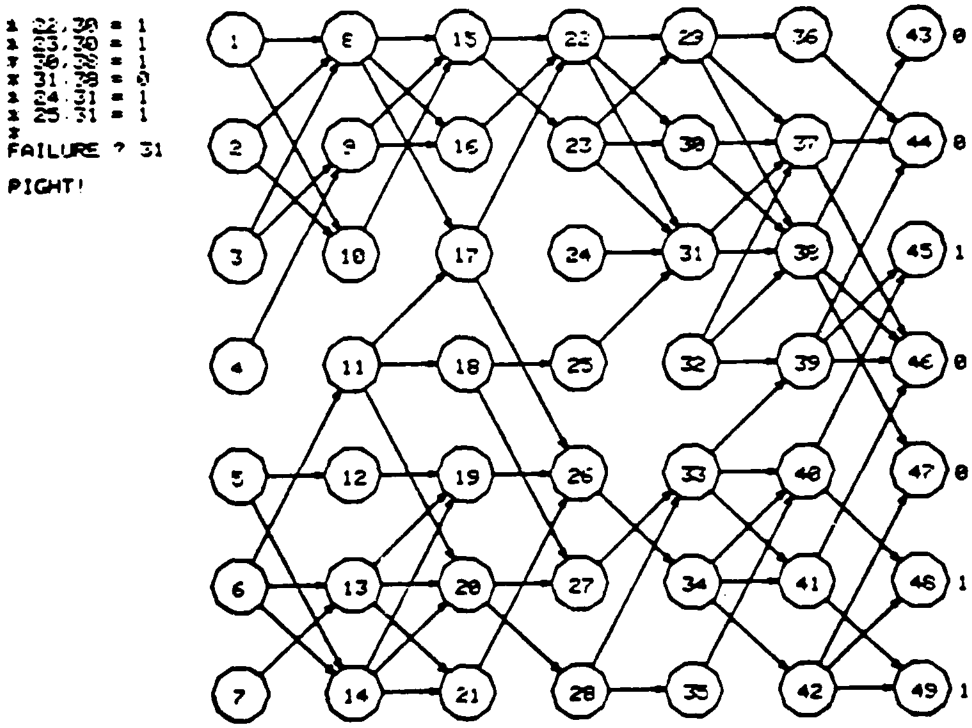

Figure 7. A simple context-free task (from Rouse, Rouse, Hunt, Johnson, & Pelligrino, 1980).

The task of the student is to determine which component has failed. Students test arcs until the failed component is found. The final outputs of the network are shown on the right side of the display. The upper left corner shows the actions taken by a student working on this problem. The student first tested arc 22, 30 and obtained an output of 1. On the fourth test (arc 31, 38) a 0 (faulty) output was found. The next two tests allowed the student to determine that the failed component was number 31. The student entered the answer and was told that the response was correct.

When computer aiding is used with this task, the student is provided with an automated record-keeping system. An aiding algorithm uses the structure of the network and the known outputs to eliminate those components that could not be faulty. These components are "X'ed out" on the computer display. As the student makes further tests, additional components are eliminated. To illustrate how this could be done, note that, even before any tests are made, components 45, 48, and 49 in Figure 7 are known to be good, because each of them has a 1 output. Any components having an input to those components must also be good, because all of the inputs to components 45, 48, and 49 must be 1 to get an output of 1. Thus, components 39, 40, 41, and 42 can also be eliminated. Additional components can be eliminated by working backward through the circuit.

In Task 1, outputs are always fed forward to components of the same type. Real systems have different types of components, and often have feedback loops. Task 2, presented in Figure 8, is a more complex context-free task incorporating two types of components and feedback loops. The rectangular components are AND gates, identical to the components of the simple task. The six-sided components are OR gates. OR gates produce an output of 1 if <u>any</u> of their inputs is 1 and they have not failed. Feedback loops are also present. For example, component 7 sends its output backward through the network to component 5. The student's task is the same as in Task 1.

The complexity of both of these tasks is easily varied by changing the number of components.

In order to assess the transfer of training from these context-free tasks to equipment-specific tasks, a system to simulate a variety of items of real equipment was developed. This system is called FAULT (Framework for Aiding the Understanding of Logical Troubleshooting). FAULT has two components. The first is a hard-copy schematic of the equipment, such as the Turboprop Powerplant shown in Figure 9. The second component is an interactive display, shown in Figure 10.

The student is initially given the general problem symptoms; for example, the engine turns over but will not start. The student can then make inquiries about the functions of the system components; collect information about the functions of those components by checking gauges, making continuity checks, and removing components for bench tests; and replace components. Each action has a cost based on the time that the action would require and, for replacements, the cost of the replacement item. Students are instructed to repair the system at the lowest possible cost.

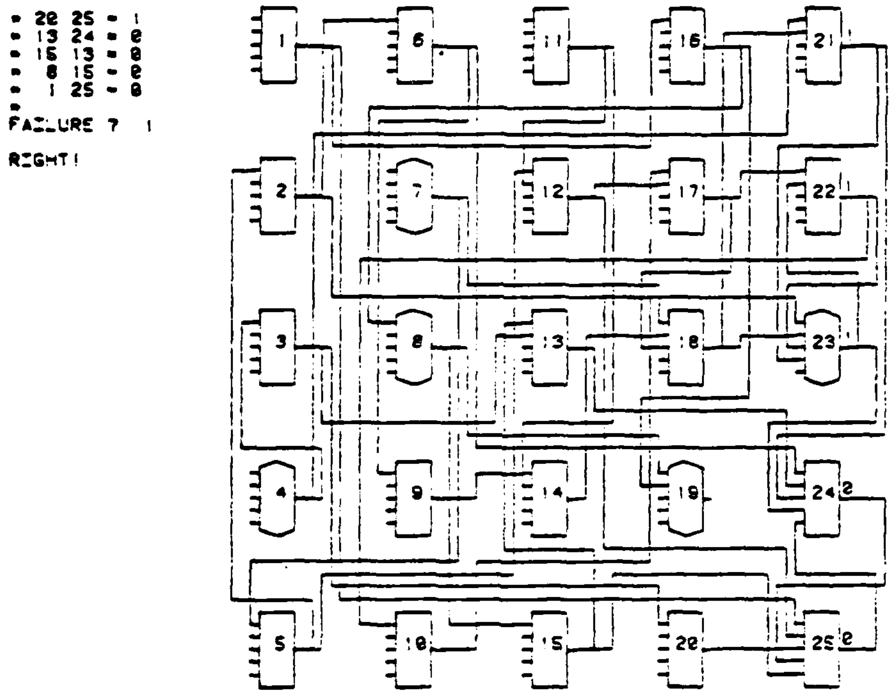

Figure 8. A complex context-free task (from Rouse et al., 1980).

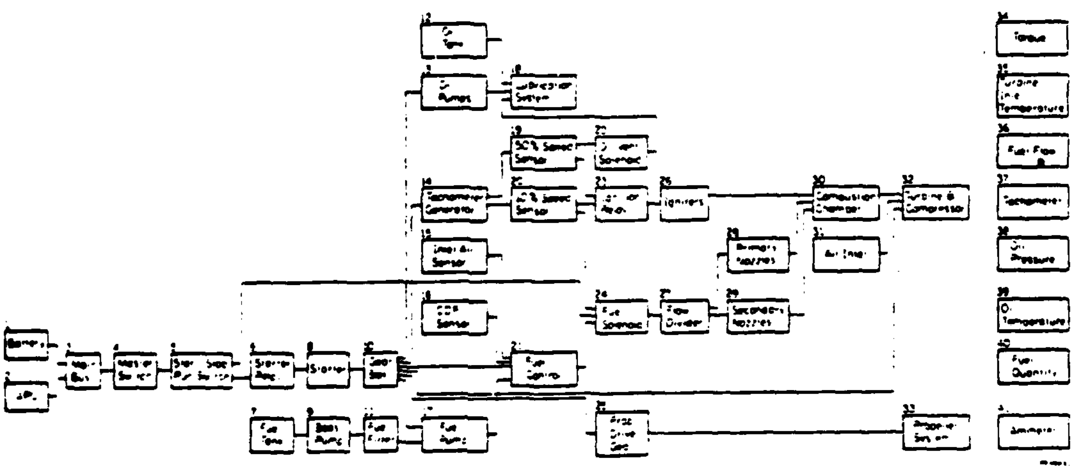

Figure 9. Turboprop engine schematic (from Rouse et al., 1980).

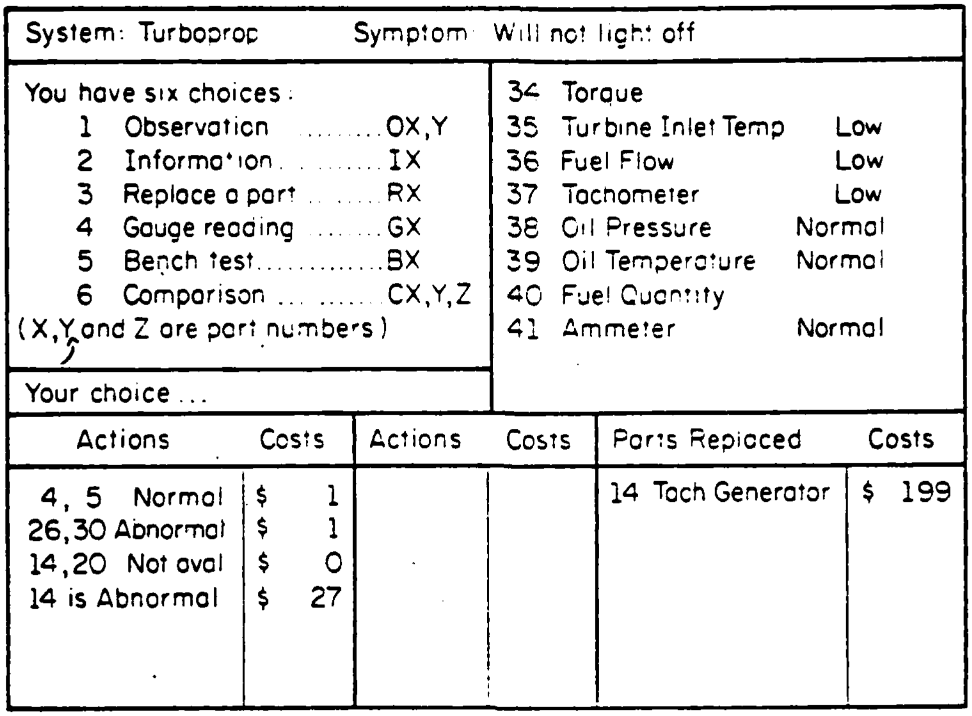

Figure 10. FAULT interactive display (from Rouse et al., 1980).

The Research

Five experiments have been completed. Each examined aspects of the context-free tasks and their use for training. The first experiment used only the simple task (Task 1). Students solved problems having either 9, 25, or 49 components in a transfer-of-training design in which half of the students first used computer aiding and then transferred to the unaided task. The remaining students were first trained without computer aiding and then transferred to the aided task. The results indicated that the number of tests required to reach a correct solution increasingly deviated from the optimal solution as problem size increased. Computer aiding resulted in a lower number of tests to solution during the training trials, but not during the transfer trials. Computer aiding during training therefore enhanced subsequent unaided performance.

In the second experiment the effects of requiring the students to operate under time constraints were examined. The time available to complete each problem was limited to either 30, 60, or 90 seconds. (It is relatively easy to solve these problems consistently in 90 seconds, but very difficult to do so in 30 seconds.) A clock was added to the display to give the students continuous knowledge of the amount of time remaining. Task 1 was used. Again, half the students had computer aiding only during the first half of the experiment. The others had computer aiding only during the second half. All problems had 49 components. Students used more tests than were necessary to solve the problems, and the effects of computer aiding did not transfer to the unaided condition. The interpretation of these results is that forced-paced

students employ less information, including study of the computer aid, than do self-paced students.

The first two experiments used engineering students as subjects. Experiment 3 used 40 fourth-semester trainees from the University of Illinois Federal Aviation Administration (FAA) Certificate Program in Aircraft Powerplant Maintenance. The design was the same as the first experiment, with the exception that transfer was examined in only the aided-unaided direction. The results were identical to those of Experiment 1: More tests, relative to the optimal solution, were required as problem size increased; computer aiding improved performance during training; and computer aiding enhanced subsequent performance on the unaided task.

The fourth experiment examined the effects of computer aiding during Task 1 performance on subsequent Task 2 performance. Forty-eight first-semester aviation mechanic trainees served as subjects. In two respects, Task 1 performance was similar to that found previously: Performance declined as problem size increased, and computer aiding during training improved performance. However, there was no transfer of training from the aided to the unaided Task 1 displays. Such transfer had been shown by fourth-semester students in Experiment 3. A possible interpretation of this finding is that the less-experienced first-semester students may have been using the computer aiding only as a way to make the task easier, rather than trying to understand how the aiding was helping them. Transfer of training was shown between Tasks 1 and 2 in terms of the amount of time taken to reach the correct solution, but not in terms of the number of tests made. Initially, the students who had received computer aiding in Task 1 performed worse on Task 2 than those who had received no Task 1 aiding, but eventually these differences were reversed. The cause of this effect is not clear.

Experiment 5 examined the students' ability to transfer skills developed on Tasks 1 and 2 to FAULT equipment-specific simulations. Subjects were fourth-semester trainees from the FAA Certificate Program. In this experiment both Tasks 1 and 2 were used as training tasks and transfer to three items of simulated equipment was assessed. Students trained with computer aiding on the context-free tasks were able to solve the equipment-specific problems at a lower total cost than those students who had not received computer aiding. These students used fewer high-cost procedures, such as bench tests, and used the free information available in gauge readings more frequently.

In summary, these experiments demonstrate that positive transfer does take place between the two levels of context-free tasks and, more important, from the context-free tasks to the equipment-specific simulations. This transfer is most pronounced when students can work on the problem at their own pace using computer aiding. It also appears that students have difficulty using correct (1) outputs efficiently. Computer aiding assists them in making use of this information.

Future Directions

Future research will continue to investigate the effects of computer aiding, attempt to define problem complexity, and develop cognitive models

of diagnostic performance. The major thrust of this research will be a continuation of the transfer studies to determine the degree of transfer from context-free tasks and equipment-specific simulations to hands-on, actual-equipment troubleshooting.

ADAPTIVE COMPUTERIZED TRAINING SYSTEM

Background

The previously discussed research is concerned with providing non-equipment-specific diagnostic training through the use of non-equipment-specific diagnostic tasks. The following research is directed toward providing non-equipment-specific training using an equipment-specific task. This effort is called the Adaptive Computerized Training System (ACTS).

The ACTS also adds a new component to the training process--student and expert performance are modeled and these student and expert models are used to provide instructional feedback to the student and to direct the training process. This requires the use of artificial intelligence techniques.

Artificial Intelligence (AI) techniques are algorithms (rules) that enable computers to exhibit "intelligent" behavior. Examples of intelligent behavior are understanding written English, playing chess, and learning (changing behavior as a result of experience). The AI techniques can provide individualized instruction but do not require separate programing of the instructional logic for each lesson. Extensive computer resources, however, are required to support the use of AI techniques. In the past, this requirement has prevented the use of such systems outside a research environment.

The primary objective of the ACTS research effort is to improve the individualization of maintenance training through the use of some basic AI techniques that can be implemented on small-scale inexpensive computer systems.

ACTS Description

The student's task in ACTS training is to troubleshoot an electronic circuit by making various test measurements and replacing the malfunctioning part. The entire process is simulated by the ACTS. Neither the actual circuit nor test equipment is required. The heart of the system is an adaptive computer program that models the student's behavior, compares the model of the student to that of an expert, and provides feedback to the student to make his or her behavior more like that of the expert.

The ACTS is not being proposed as a complete troubleshooting training method. It will not train the student to use test equipment or to assemble or disassemble the equipment. It is designed to train the student in decision making during the troubleshooting process.

The ACTS consists of four major components: (a) the task model, (b) the expert model, (c) the student model, and (d) the instructional model.

Task Model. The task model is a simulation of the circuit on which the student is to be trained. The circuit currently being used is a modular version of the Heathkit IP-28 Power Supply.[1] A simplified diagram of this circuit is shown in Figure 11. The power supply, when functioning properly, converts an alternating current input (shown at the left) into a stable, low-voltage, low-amperage output (shown at the right). The circuit consists of 10 modules. Since the output of the circuit must be stable, even with variations in the input, there are a number of corrective feedback loops in the circuit.

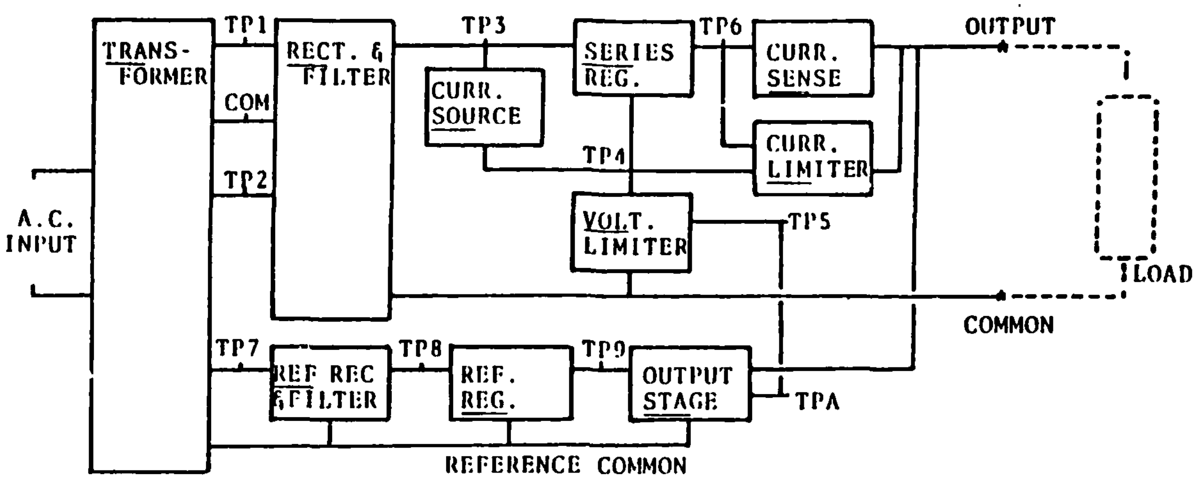

Figure 11. Circuit diagram.

Expert Model. The second major component of the ACTS is a model of an expert troubleshooter. This model predicts the expert's measurement choices while troubleshooting the circuit. It is developed through on-line observation by the computer of the expert's troubleshooting behavior.

Student Model. The student model is a decision model that predicts the student's measurement choices. It is developed through on-line observation by the computer of behavior as the student solves troubleshooting problems on the ACTS.

Instructional Model. The instructional model compares the expert and student models, determines discrepancies between the two, provides feedback, and modifies the instructional sequences for the student in order to reduce these discrepancies.

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[1]Commercial designations are provided only for precision of description. Their use does not constitute endorsement by the Department of the Army or the Army Research Institute.

Modeling Behavior

The uniqueness of the ACTS lies in the use of the student and expert models. While the student and expert models serve different functions and use different data, their operation is identical. The original version of the ACTS used an Expected Utility (EU) approach to create the student and expert models. The current version uses a Multi-Attribute Utility (MAU) approach. Both approaches "observe" human behavior and, through the use of adaptive algorithms, derive sets of numbers that permit reproduction of that behavior. In the EU model, these numbers represent the human's relative preference for the outcomes of the actions that can be taken during the diagnostic process. An action can be either a measurement or a module replacement. The EU model, however, has two drawbacks. First, behavior is represented by a large set of numbers--at least two for every action that can be taken. Second, the feedback that can be provided on the basis of this model is limited to indicating too high a preference or too low a preference for various actions. Thus, a new model for the ACTS was sought to reduce computations and increase feedback precision.

In the MAU model, a much smaller set of numbers is used. Each represents an "attribute," or a general characteristic common to all actions. The three attributes currently being used are Decrease in Uncertainty, Fault Isolation, and Cost. Decrease in Uncertainty is the proportion of possible faults that is expected to be eliminated by an action. Fault Isolation is the proportion of possible faulty modules that is expected to be eliminated by an action. This differs from Decrease in Uncertainty because most modules can be faulty in several ways. Cost is the dollar cost of an action, based on the time required to take the action and the cost of replacement parts. The use of the MAU model makes it possible to provide students with "higher order" feedback based on their relative preferences for action attributes. For example, a student can be told that too little emphasis is being placed on the cost of the actions being considered.

Developing ACTS Training

Preparation of the ACTS for training requires five steps, or tasks. First, a matrix showing the relationships between the possible faults and the resulting measurement outcomes must be prepared. A sample is shown in Figure 12. An "L" indicates a lower than normal outcome, an "H" indicates a higher than normal outcome, and a blank indicates a normal outcome.

The second task is to determine the probability of occurrence of each possible fault. This can be done by examining maintenance records, consulting experts, or simply assuming that all faults are equally likely.

The third task is to determine the cost of each measurement and module replacement. The cost should include both the time required to take an action and the cost of any replacement parts.

Fourth, the computer must be programed to display the circuit diagram, and the fault matrix, fault probabilities, and action costs must be entered.

MODULE FAULTS		CIRCUIT OPERATING CONDITION																															
		VOLTAGE REGULATION											CURRENT REGULATION											POWER OFF									
		OUT	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA	OUT	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TPA
MODULE	FAILURE	DC	AC	AC	DC	DC	DC	DC	AC	DC	DC	DC	DC	AC	AC	DC	DC	DC	DC	AC	DC	DC	DC	RE	RE	RE	RE	RE	RE	RE	RE	RE	RE
LIM	OPN TRAN												H				H	H	H														
LIM	SHT TRAN	L				L	L	L					L				L	L	L								L						
REC	OPN OUT	L			L	L	L	L					L			L	L	L	L														
REG	OPN RES	L				L		L			L	L	L				L	H	L			L	L										
REF	OPN DIODE	L				L		L		L	L	L	L				L	H	L		L	L	L										
SEN	SHT RES												H				H	H	H														
SER	OPN TRAN	L				H	L	L					L				H	L	L														
SHU	Ø OUT	L				L	L	L					L				L	L	L														
STA	OPN RES	H				H	L	H				L						H					L										H
STA	SHT RES	H				H		H				L						L					L										L
TRA	OPN OUT	L	L	L	L	L	L	L					L	L	L	L	L	L	L					H	H								
TRA	Ø REF OUT	L				L		L	L	L	L	L	L				L	H	L	L	L	L	L							H			
VOL	OPN TRAN	H				H	H	H				L																					
VOL	SHT	L				L	L	L					L				L	L	L								Ø						

BLANK SPACE IS NORMAL; L = LOW; H = HIGH; Ø = ZERO.
MEASUREMENTS TP1 TO TP6 MADE IN REFERENCE TO COMMON. MEASUREMENTS TP7 TO TPA MADE IN REFERENCE TO REFERENCE COMMON.

Figure 12. Sample ACTS fault matrix (from Hopf-Weichel et al., 1980).

The fifth and final step is to train the expert model. This consists of having a human expert solve a series of troubleshooting problems on the ACTS. During this step the expert model learns the human expert's preferences. When this is completed, the human expert is no longer needed. The expert model on the computer is ready to begin training the student. This process will be examined from the viewpoint of the student.

Training Sequences

After receiving introductory training on the operation of the circuit, the student is presented with a display similar to that shown in Figure 13. A simplified circuit diagram is shown at the top of the display. The lower left section contains a table used to present measurement results. The measurement points (OUTPut, Test Point 1, etc.) form the rows of this table. The types of measurement taken (VOLtage, CURrent, and RESistance) are shown in the columns.

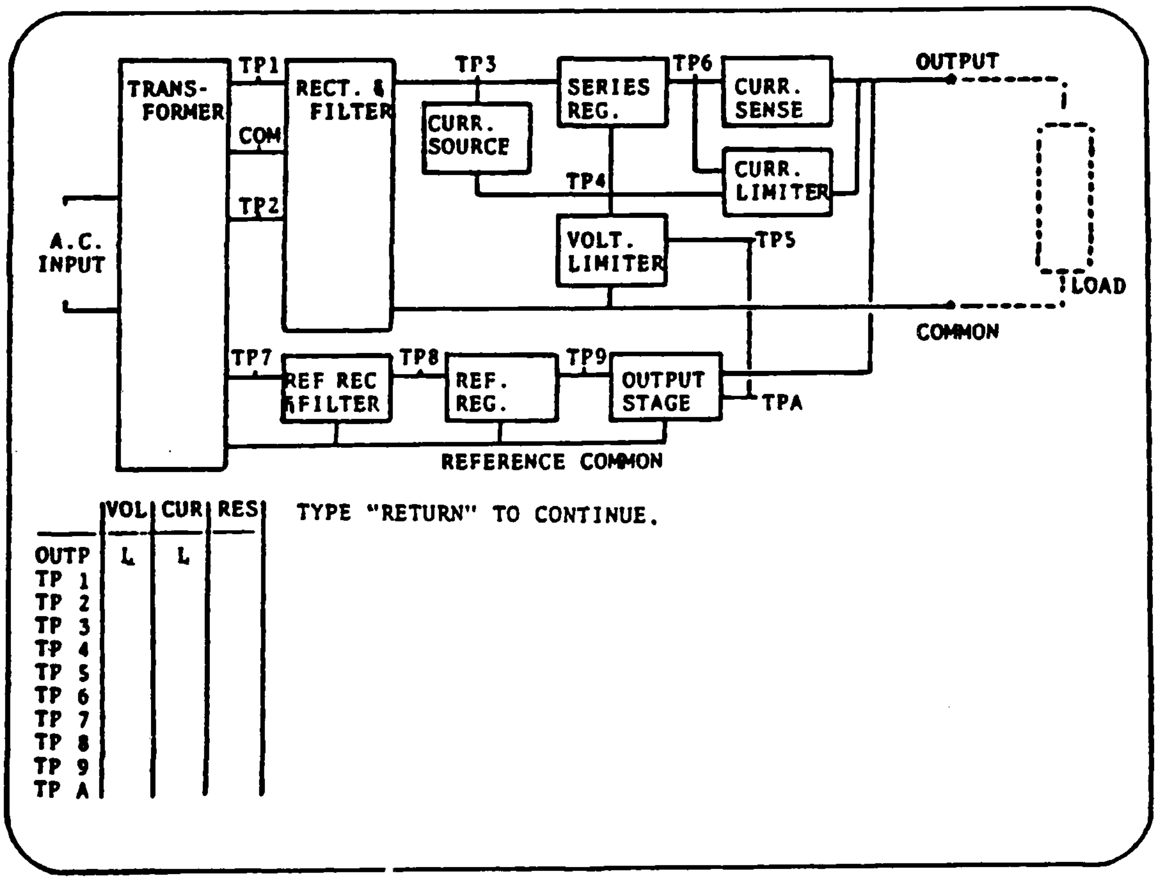


Figure 13. Student display at the start of a problem (from Hopf-Weichel et al., 1980).

The results of the measurements taken at the output of the circuit are automatically provided to the student at the start of a problem. The student is then asked to list the four best actions to take. Help from the expert may also be requested at this time. In the display shown in Figure 14, the student has selected four possible actions and has been shown the values of the three attributes for each action. The first action being considered, TP9DCVR (a direct current measurement at TP 9 with the circuit operating in a voltage regulation state), is expected to eliminate 40% of the possible faults and 33% of the possible faulty modules. It will cost $4.00. The fourth action considered, TRA (replace the transformer), is expected to eliminate 28% of the possible faults and 19% of the possible faulty modules by eliminating the possibility that the transformer could be bad. This action will cost $98.00. The student chooses to take the third action, TP4REPO (a resistance measurement between TP4 and common with the power off), which is the best action in terms of Decrease in Uncertainty and Fault Isolation. The result of this action, a normal outcome, is shown in the table at the left of the display.

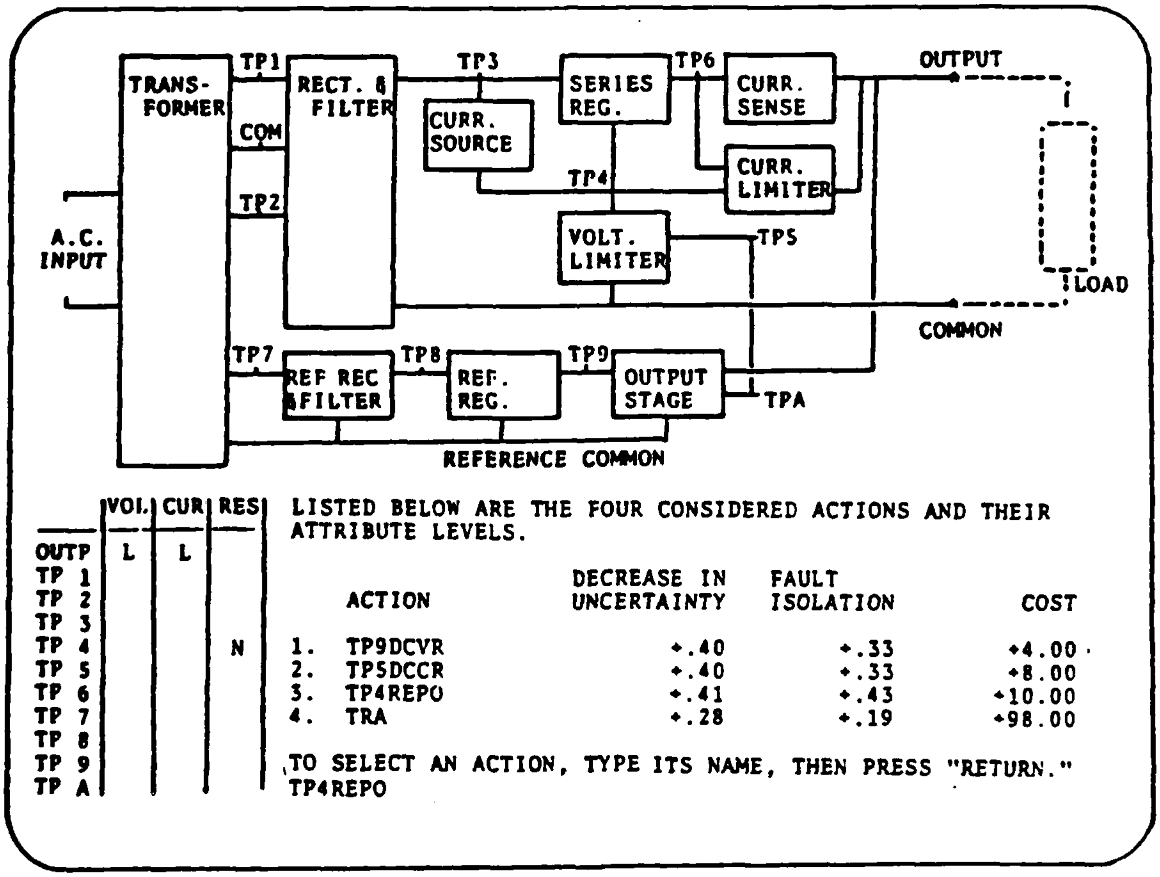


Figure 14. Student display after the student has selected an action (from Hopf-Weichel et al., 1980).

If the student requests help, the expert provides a list of the four best actions to take. This is followed by more detailed information about those actions, as shown in Figure 15.

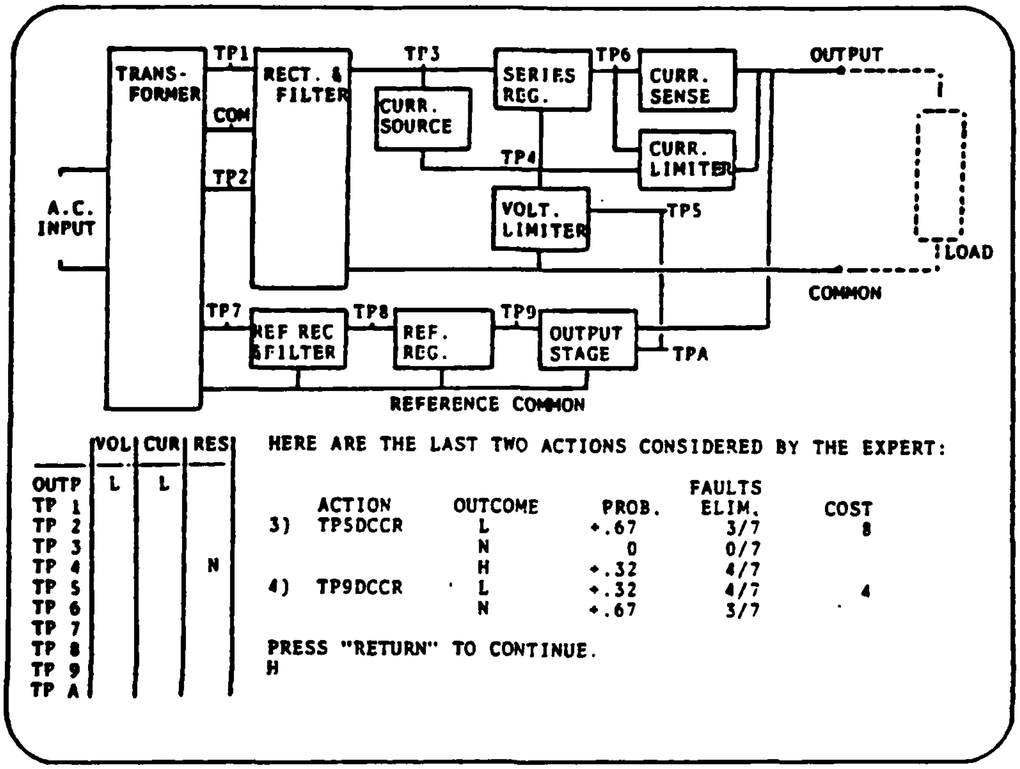
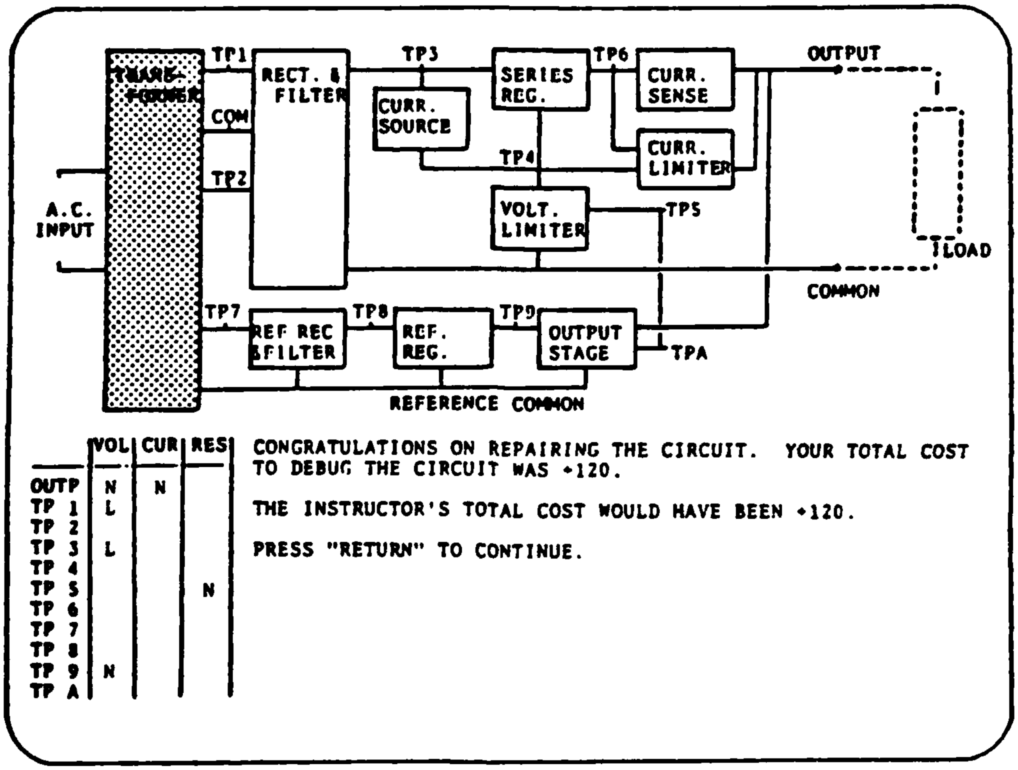


Figure 15. Student display during the Help sequence (from Hopf-Weichel et al., 1980).

The student continues to take test measurements until the faulty module has been identified, then replaces the faulty module. At the completion of the problem, the student receives two types of feedback. First, the student's cost to repair the circuit is compared with that of the expert (see Figure 16). Second, as shown in Figure 17, feedback based on a comparison of the student and expert models is provided. In this example, the student overemphasized Uncertainty Reduction and Fault Isolation, and underemphasized Cost. The student would then begin another problem, with the process continuing until the student and expert models were sufficiently similar.

Evaluation

The key question regarding the ACTS is whether it is an effective training system. Since the MAU model has just been implemented, the only data available to date have been obtained using the EU model. Three major findings were obtained. First, the "learning" algorithms in the ACTS do learn to predict human performance. If performance is perfectly consistent, the prediction of the learning algorithm will be perfect. Second, student performance



	VOL	CUR	RES
OUTP	N	N	
TP 1	L		
TP 2			
TP 3	L		
TP 4			
TP 5			N
TP 6			
TP 7			
TP 8			
TP 9	N		
TP A			

Figure 16. Cost-based feedback (from Hopf-Weichel et al., 1980).

improves with practice on the system, even when no feedback based on the student model is provided. Third, simulation studies have shown that similar sets of utilities produce similar troubleshooting strategies, while dissimilar sets of utilities produce dissimilar troubleshooting strategies. This is a necessary prerequisite for the use of differences between two sets of utilities (student and expert) as a basis for instructional feedback.

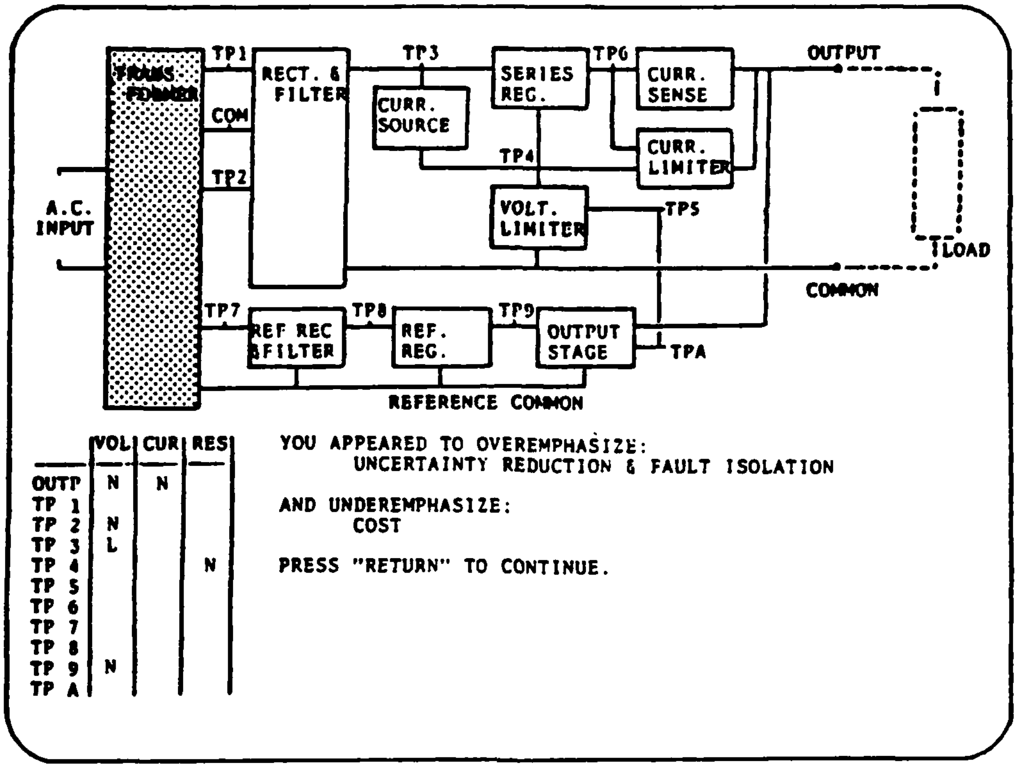


Figure 17. Model-based feedback (from Hopf-Weichel et al., 1980).

Future Directions

Future research on the ACTS will initially establish the training effectiveness of the ACTS. Research will include the investigation of transfer of ACTS training to actual equipment, the effects of varying the problem presentation sequence on the basis of student performance, and the effects of providing varying mixes of ACTS and actual-equipment training. Once this initial research is complete, the cost and training effectiveness of the ACTS in an ongoing course of instruction at an Army school will be determined.

SUMMARY

The Army's need for improved methods of providing maintenance training is expected to become more acute during the next two decades. At the same time, advances in computer technology are expected to result in low-cost

computer systems that can be used for training. Although such systems have the potential to provide improved maintenance training, little guidance for utilizing this potential effectively currently exists. The three research efforts just described are attempts to develop that guidance. Each of the efforts is concerned with developing ways to train students to diagnose equipment malfunctions efficiently. Each uses computer technology to provide individualized instruction, realistic graphic displays, and simulation of maintenance tasks. Each uses a different training approach: games, context-free simulations, and computerized experts. Ultimately, this research should produce ways to provide students with general troubleshooting skills that can be applied to the variety of items of equipment that they will have to repair on the job.

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